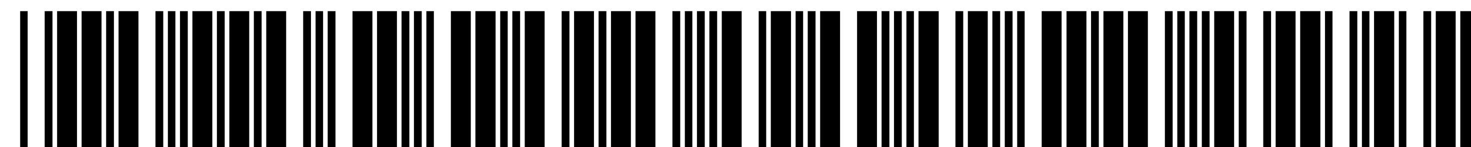

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(54) **APPARATUS AND METHOD TO CONTROL ION BEAM CURRENT**

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(51) **Int. Cl.**

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G21K 1/08	(2006.01)
H01J 37/317	(2006.01)
H01J 37/08	(2006.01)
H01J 37/10	(2006.01)

(52) **U.S. Cl.**
CPC ***H01J 37/08*** (2013.01); ***H01J 37/10*** (2013.01); ***H01J 37/3171*** (2013.01); *H01J 2237/0473* (2013.01); *H01J 2237/0475* (2013.01)

(58) **Field of Classification Search**
USPC 250/269.1, 281, 282, 288, 306, 491.1, 250/492.1, 492.11, 492.21, 492.2, 592.3, 250/492.23, 526
See application file for complete search history.

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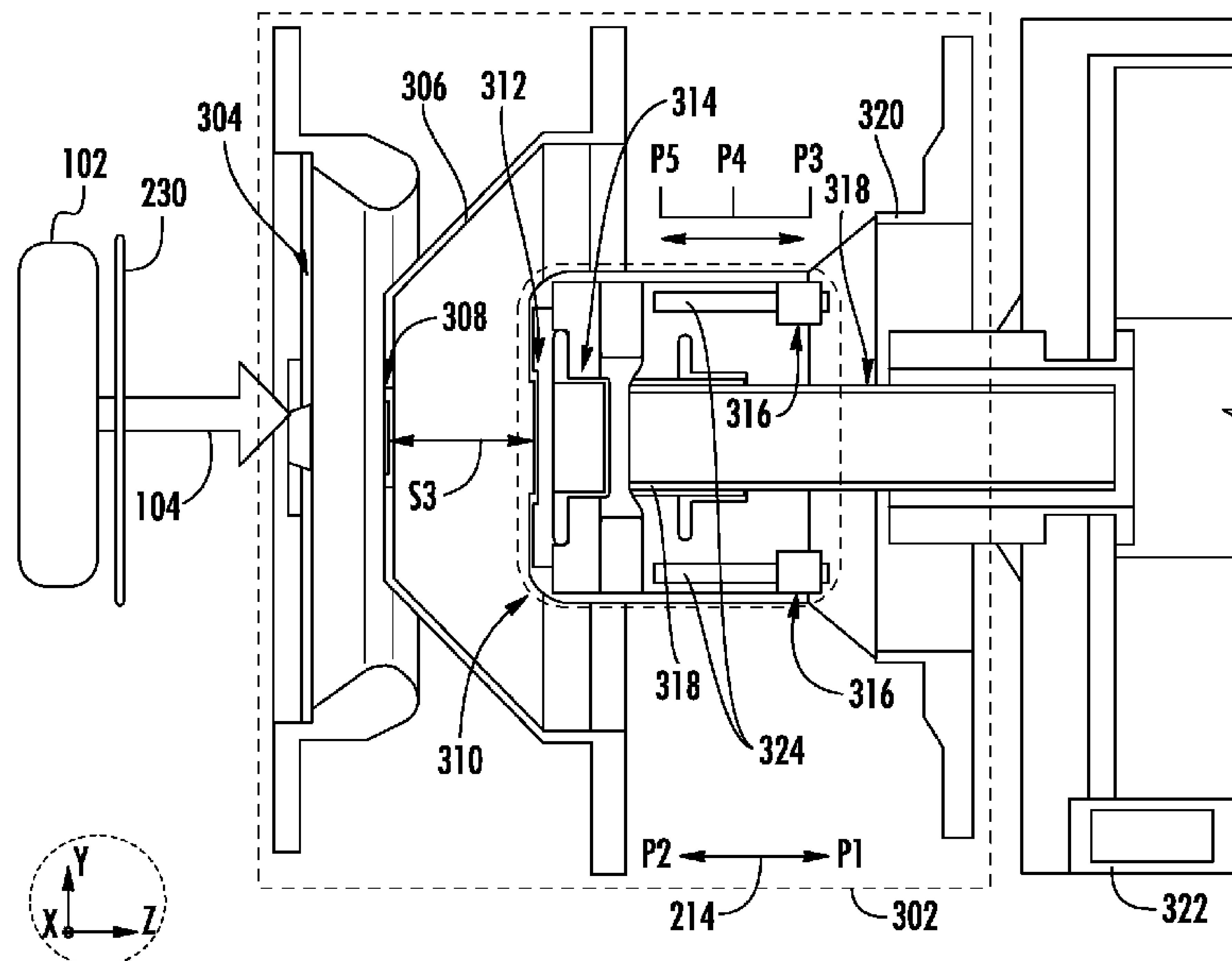
Primary Examiner — Bernard Souw

(57) **ABSTRACT**

An apparatus to control an ion beam for treating a substrate. The apparatus may include a fixed electrode configured to conduct the ion beam through a fixed electrode aperture and to apply a fixed electrode potential to the ion beam, a ground electrode assembly disposed downstream of the fixed electrode. The ground electrode assembly may include a base and a ground electrode disposed adjacent the fixed electrode and configured to conduct the ion beam through a ground electrode aperture, the ground electrode being reversibly movable along a first axis with respect to the fixed electrode between a first position and a second position, wherein a beam current of the ion beam at the substrate varies when the ground electrode moves between the first position and second position.

19 Claims, 5 Drawing Sheets



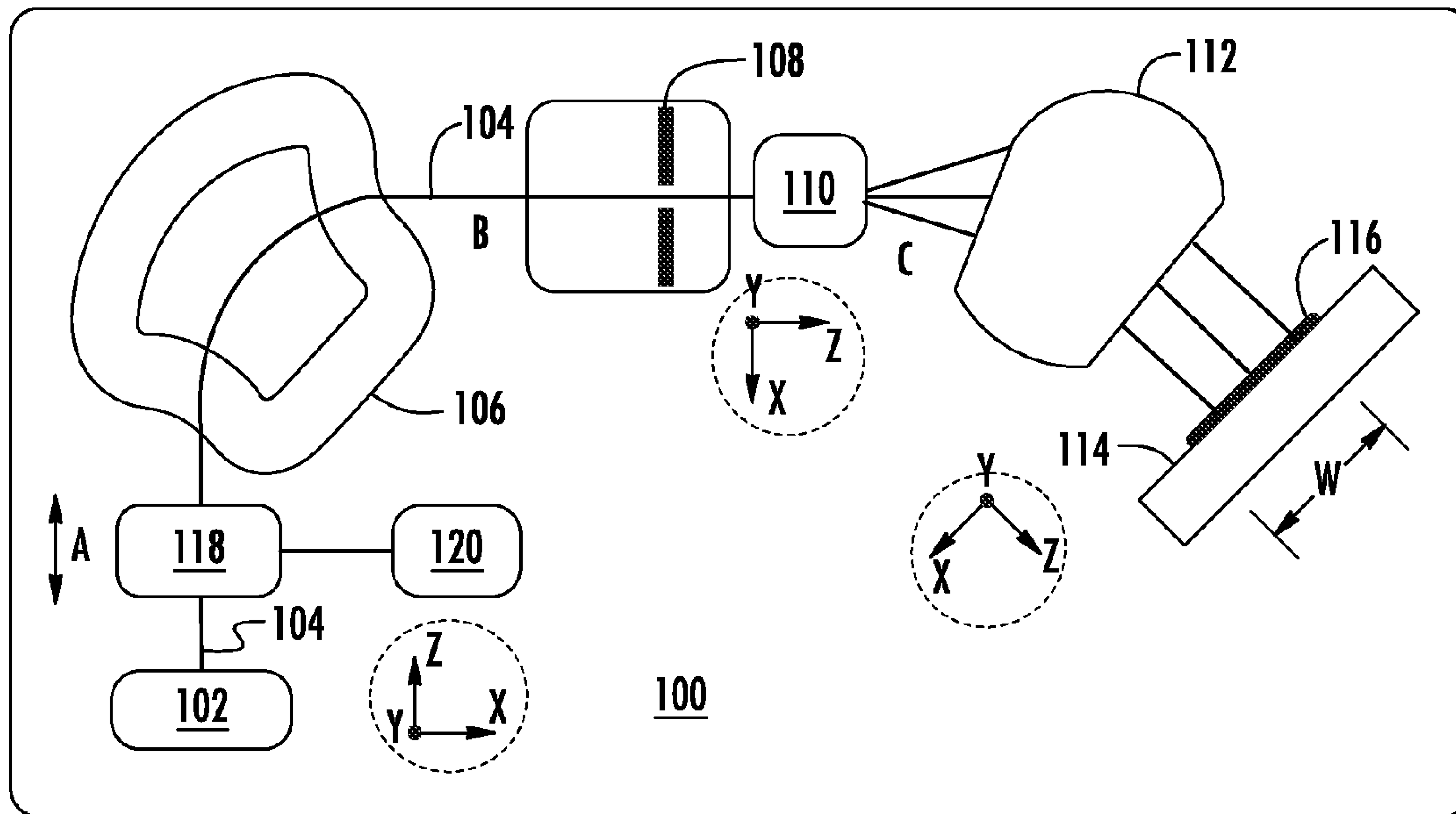


FIG. 1

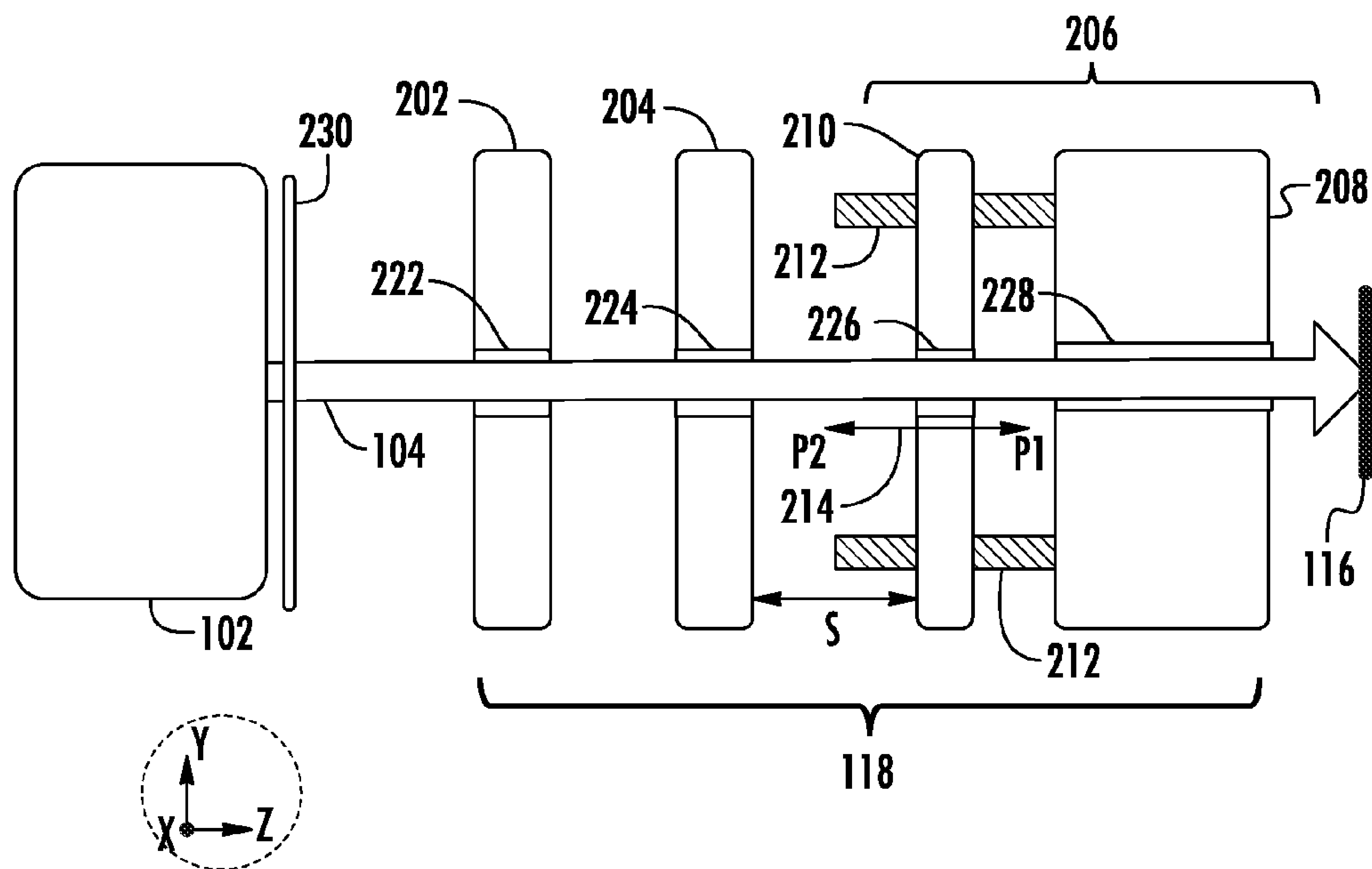


FIG. 2

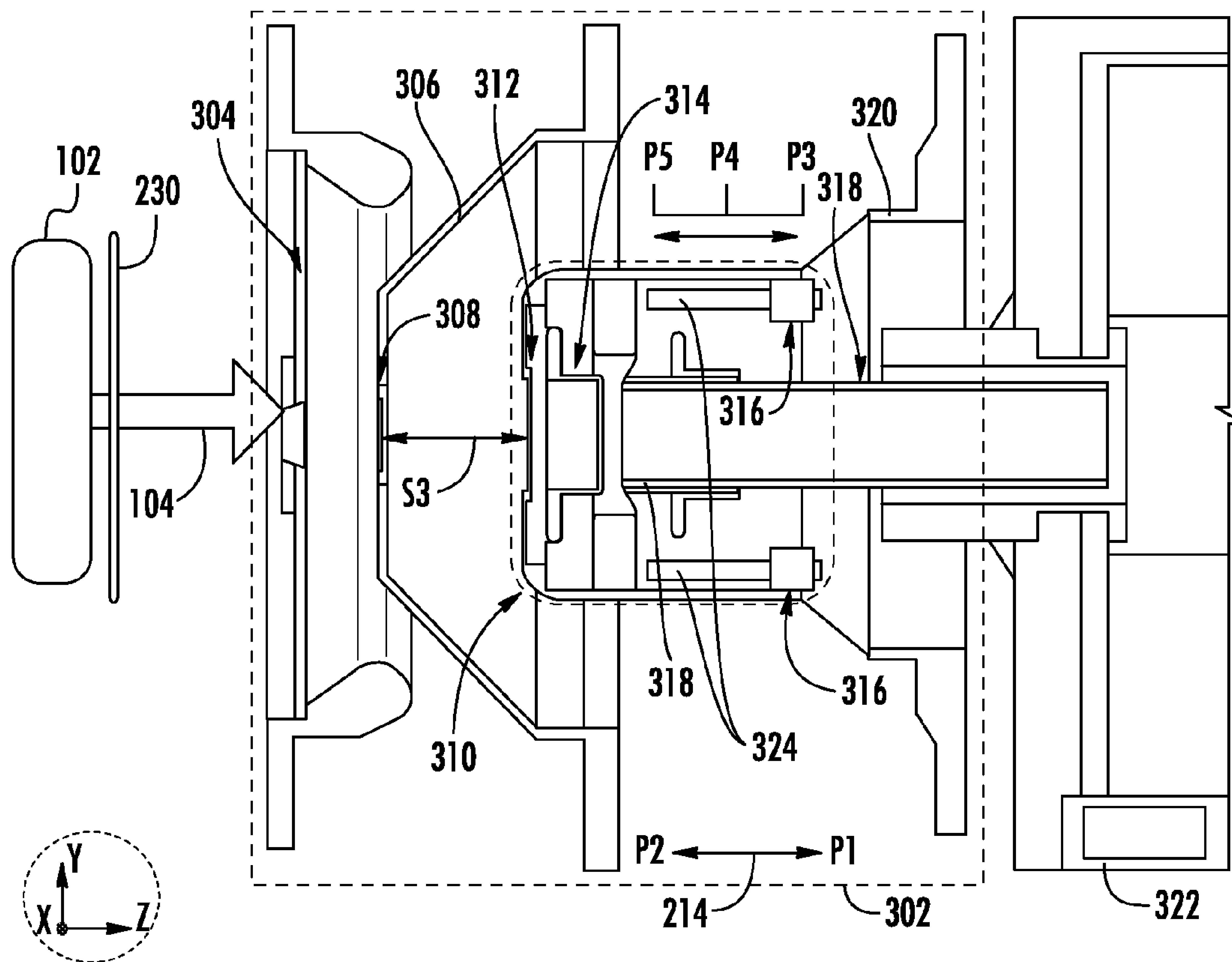


FIG. 3A

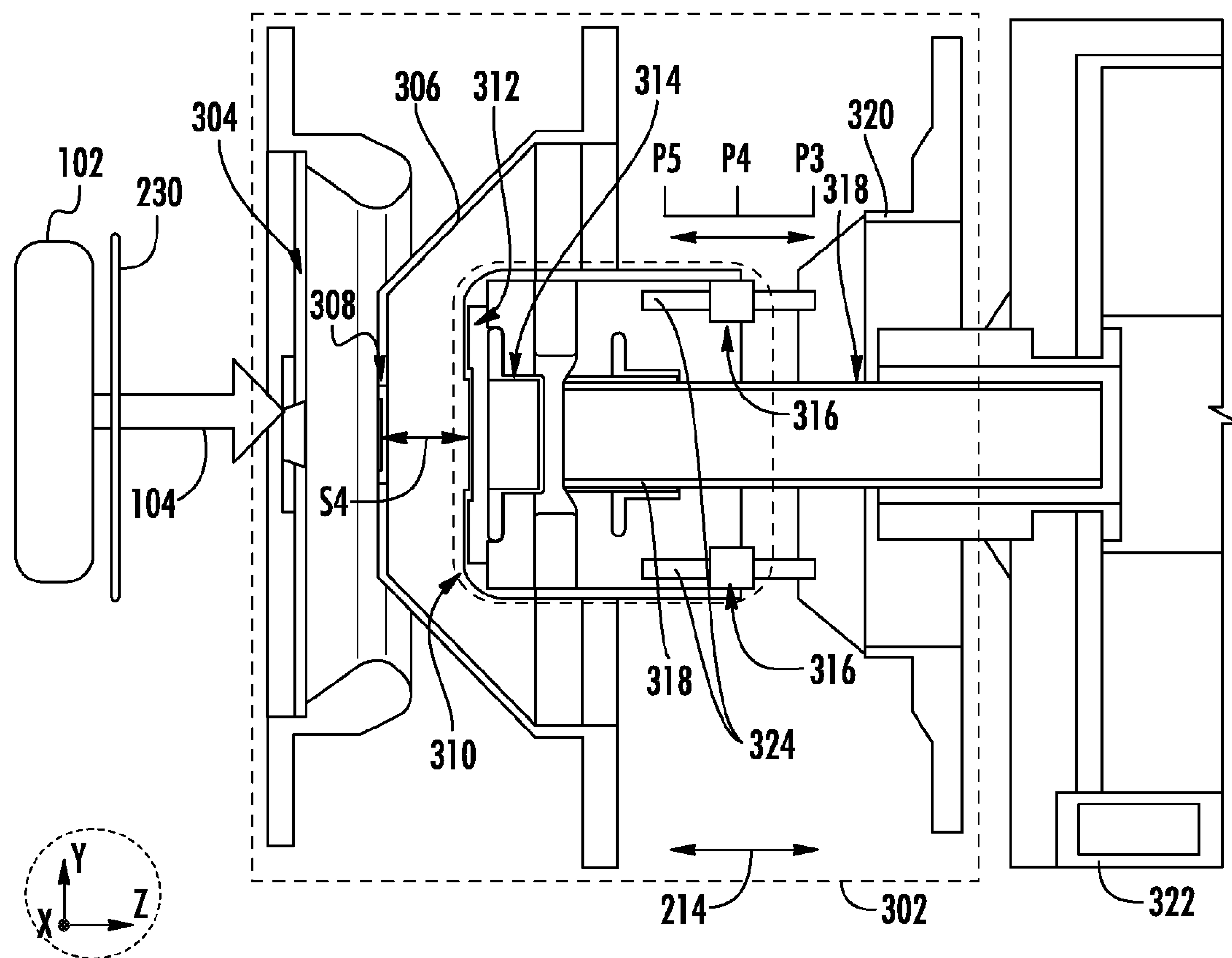


FIG. 3B

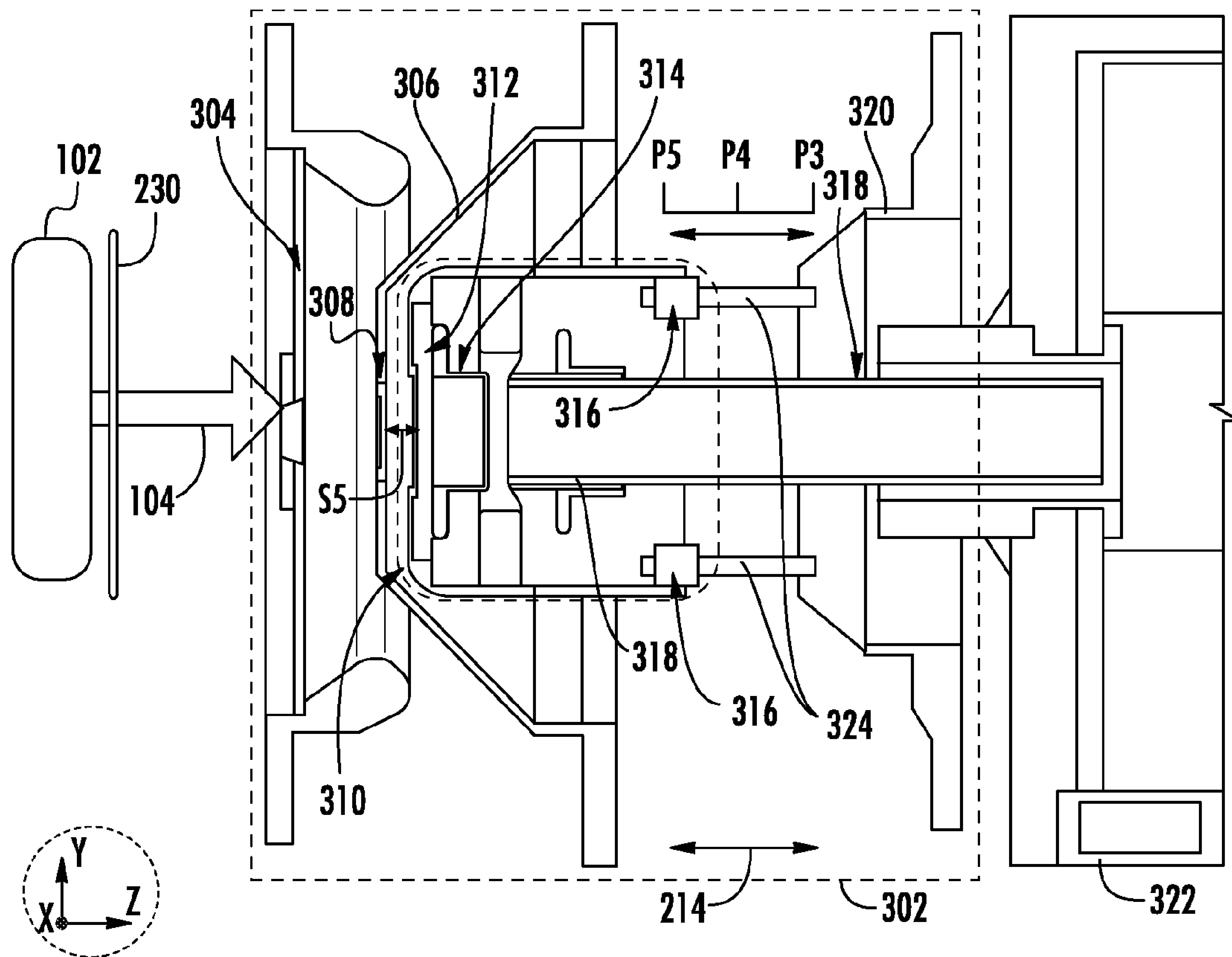


FIG. 3C

400

GENERATE ION BEAM USING ION SOURCE
402

ARRANGE GROUND ELECTRODE AN ADJUSTABLE ACCEL/DECEL COLUMN AT FIRST POSITION
404

APPLY FIRST FIXED ELECTRODE POTENTIAL TO ION BEAM AT FIXED ELECTRODE OF THE ADJUSTABLE ACCEL/DECEL COLUMN DISPOSED ADJACENT TO AND UPSTREAM OF GROUND ELECTRODE WHEN GROUND ELECTRODE IS DISPOSED AT FIRST POSITION
406

APPLY SECOND FIXED ELECTRODE POTENTIAL LESS THAN FIRST FIXED ELECTRODE POTENTIAL TO ION BEAM AT FIXED ELECTRODE
408

RECEIVE USER INPUT IN DRIVE COMPONENT
410

MOVE GROUND ELECTRODE TO SECOND POSITION, WHEREIN GROUND ELECTRODE AND FIXED ELECTRODE DEFINE FIRST GAP IN FIRST POSITION AND A SECOND GAP IN SECOND POSITION SMALLER THAN FIRST GAP
412

FIG. 4

APPARATUS AND METHOD TO CONTROL ION BEAM CURRENT

FIELD

The present embodiments relate to ion beam apparatus, and more particularly, to components and methods to control ion beams in beamline ion implanters.

BACKGROUND

In the present day, ion implanters are often constructed to optimize implantation according to a specific set of applications. In some applications, for example, it may be useful to increase beam current to increase throughput of substrates to be implanted. Some beamline ion implanters may be employed to implant substrates over a range of energies, such as between 1 keV and 300 keV. This capability provides flexibility for processing substrates such as silicon wafers, for example, in circumstances where the silicon wafers are scheduled for various implants at differing ion energies. In order to define an implant energy, an ion beam may be subject to acceleration and deceleration by various components in a beamline ion implanter between an ion source and substrate to be implanted.

In an ion implanter used for ion implantation over a wide range of energies, such as between 1 keV and 300 keV, it may be convenient to extract ions from an ion source at a target energy, such as 50 keV, regardless of the target ion implant energy to be imparted to ions implanted into a substrate. This practice may ensure adequate beam current is extracted from an ion source, even for low energy implantation, since the extraction current I has a dependence upon extraction voltage V, wherein I is proportional to $V^{3/2}$ in accordance with the Child-Langmuir law. Accordingly, an ion beam having an initial ion energy of, for example, 50 KeV or greater may be received by an acceleration/deceleration column (accel/decel column) configured to adjust beam potential (beam voltage) of the ion beam in order to impart a target beam energy to the ion beam. The accel/decel column may include multiple electrodes configured to adjust beam potential and shape the ion beam.

In order to ensure stable operation, the electrode separation of various electrodes in an accel/decel column may be set at a adequate distance to prevent electrical breakdown or arcing, a process tending to increase at higher voltages. Accordingly, the electrode separation between a ground electrode and focus electrode of an accel/decel column may be set to avoid arcing at a highest operating voltage for an ion implanter, such as 300 kV. This practice may result in undesirably lower current extracted for lower ion energies. It is with respect to these and other considerations the present improvements have been needed.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended as an aid in determining the scope of the claimed subject matter.

In one embodiment an apparatus control an ion beam for treating a substrate may include a fixed electrode configured to conduct the ion beam through a fixed electrode aperture and to apply a fixed electrode potential to the ion beam, a ground electrode assembly disposed downstream of the fixed

electrode. The ground electrode assembly may include a base and a ground electrode disposed adjacent the fixed electrode and configured to conduct the ion beam through a ground electrode aperture, the ground electrode being reversibly movable along a first axis with respect to the fixed electrode between a first position and a second position, wherein a beam current of the ion beam at the substrate varies when the ground electrode moves between the first position and second position.

In another embodiment, an ion implanter may include an ion source to generate an ion beam for treating a substrate, an extraction electrode to extract the ion beam at an initial beam potential, and an adjustable accel/decel column configured to receive the ion beam and to adjust the initial beam potential. The adjustable accel/decel column may include a focus electrode configured to conduct the ion beam through a focus aperture and to apply a focus electrode potential to the ion beam, and a ground electrode assembly disposed downstream of the focus electrode. The ground electrode assembly may include a base and a ground electrode configured to apply a ground electrode potential different than the focus electrode potential and configured to conduct the ion beam through a ground electrode aperture, the ground electrode being reversibly movable along a first axis with respect to the focus electrode between a first position and a second position, wherein a beam current of the ion beam at the substrate varies when the ground electrode moves between the first position and second position.

In a further embodiment a method of manipulating an ion beam may include generating the ion beam using an ion source; arranging a ground electrode of an adjustable accel/decel column at a first position; applying a first fixed electrode potential to the ion beam at a fixed electrode of the adjustable accel/decel column disposed adjacent to and upstream of the ground electrode when the ground electrode is disposed at the first position; applying a second fixed electrode potential less than the first fixed electrode potential to the ion beam at the fixed electrode; and, responsive to user input in a drive component, moving the ground electrode to a second position, wherein the ground electrode and fixed electrode define a first spacing in the first position and a second spacing smaller than the first spacing in the second position.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts a top plan view in block form of a ion implanter according to various embodiments;

FIG. **2** depicts a side view of an exemplary apparatus to control an ion beam;

FIG. **3A-3C** depict operation of an exemplary apparatus according to additional embodiments of the disclosure; and

FIG. **4** depicts an exemplary process flow.

DETAILED DESCRIPTION

The present embodiments will now be described more fully hereinafter with reference to the accompanying drawings, where some embodiments are shown. The subject matter of the present disclosure, nonetheless, may be embodied in many different forms and are not to be construed as limited to the embodiments set forth herein. Instead, these embodiments are provided so this disclosure will be thorough and complete, and will fully convey the scope of the subject matter to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

The embodiments described herein provide novel ion implanters, and novel apparatus and an adjustable accelera-

tion/deceleration column, also referred to herein as an "accel/decel column," is provided in a beamline ion implanter to adjust ion beam current provided to a substrate. The term "accel/decel column" as used herein refers to a component having a plurality of electrodes configured to transmit an ion beam and to apply a potential to the ion beam. The applied potential may result in increasing or decreasing the potential (voltage) of the ion beam with respect to a reference, such as ground. An accel/decel column may thus function to accelerate or decelerate an ion beam after the ion beam is extracted from an ion source to a target energy, such as a target implant energy. An accel/decel column may also function to provide a targeted beam optics over a range of ion energies and beam currents of an ion beam. Thus, an accel/decel column may operate to output an ion beam having a targeted shape, size, collimation, convergence or divergence, where the targeted entity does not vary with beam ion energy or beam current or remains within an acceptable range.

Regarding the present embodiments, the term "adjustable accel/decel column" refers to an accel/decel column having an electrode movable with respect to another electrode of the accel/decel column via operation of a drive component, including a motor, pneumatic component, or other component. The adjustable accel/decel column of the present embodiments may provide various advantages as described below. For example, a first advantageous effect involves increasing the available beam current provided to a substrate over a range of ion energies, a second advantageous effect involves providing a convenient approach to adjusting electrode separation in an accel/decel column, while a third advantageous effect involves the ability to optimize beam optics of an accel/decel column for operation over a range of ion energies and beam currents.

FIG. **1** depicts a top plan view in block form of a beamline ion implanter, shown as the ion implanter **100**, in accordance with various embodiments of the disclosure. The ion implanter **100** includes an ion source **102** configured to generate an ion beam **104**. The ion beam **104** may be provided as a spot beam or a ribbon beam having a cross-section where a beam width (along the X-direction of the Cartesian coordinate shown) is greater than the beam height (along the Y-direction). In the convention used herein, the Z-direction refers to a direction of an axis parallel to the central ray trajectory of an ion beam **104**. Thus, the absolute direction of the Z-direction, as well as the X-direction, where the X-direction lies perpendicular to the Z-direction, may vary at different points within the ion implanter **100** as shown. The ion beam **104** may travel through an analyzer magnet **106**, mass resolving slit **108**, and through a collimator **112** before impacting a substrate **116** disposed on substrate stage **114**. The substrate stage **114** may be configured to scan the substrate **116** at least along the Y-direction in some embodiments. In the example shown in FIG. **1**, the ion beam **104** may be provided as a spot beam scanned by the scanner **110** along the X-direction, in order to provide a scanned ion beam having a width comparable to the width W of the substrate **116**. In other embodiments, the ion beam **104** may be provided as a ribbon beam and the scanner **110** may be omitted. In the example of FIG. **1**, other beamline components useful for operation of the ion implanter **100** are omitted for clarity as will be apparent to those of ordinary skill in the art.

The ion implanter **100** further includes an adjustable accel/decel column **118** described in detail below. As shown in FIG. **1**, the adjustable accel/decel column **118** may be disposed at the point A between the ion source **102** and analyzer magnet **106**. In other embodiments, the adjustable accel/decel column **118** may be disposed at other locations within the ion implanter **100**, such as point B or point C. The adjustable accel/decel column **118** is coupled to a drive system **120**. The drive system **120** may adjust the position of an electrode within the adjustable accel/decel column **118** with respect to other electrode(s). This adjustability allows, among other things, the beam current in the ion beam **104** to be adjusted at a given ion energy of the ion beam **104**, as discussed below.

In various embodiments, the ion implanter **100** may be configured to deliver ion beams for "low" energy or "medium" energy ion implantation, including a voltage range of 1 kV to 300 kV, corresponding to an implant energy range of 1 keV to 300 keV for singly charged ions. As discussed below, the position of an electrode such as a ground electrode in the adjustable accel/decel column **118** may be adjusted depending upon the target voltage for ion implantation for ion beam **104**, as well as the target beam current of ion beam **104**.

FIG. **2** depicts a side view of a variant of the adjustable accel/decel column **118** according to various embodiments. In this embodiment, the adjustable accel/decel column **118** includes a terminal electrode **202**, focus electrode **204**, and ground electrode assembly **206**. In some embodiments, the adjustable accel/decel column **118** may include additional electrodes (not shown) such as a suppression electrode, as known in the art. The terminal electrode **202** may include a terminal electrode aperture, shown as the aperture **222**, in order to conduct the ion beam **104** toward a substrate (see substrate **116** of FIG. **1**). The focus electrode **204** is disposed downstream of the terminal electrode **202** and includes an aperture **224** configured to receive the ion beam **104** from the terminal electrode **202** and transmit the ion beam **104** toward the ground electrode assembly **206**. The term "downstream" as used herein refers to a position of a component positioned relatively closer to a substrate along a beam path of an ion beam with respect to another component. Likewise, the term "upstream" as used herein refers to a position of a component located relatively closer to the ion source along a beam path of an ion beam with respect to another component. The ground electrode assembly **206** is disposed downstream of the focus electrode **204** and includes a base **208** and ground electrode **210**. The base includes an aperture **228** and the ground electrode includes an aperture **226**. These apertures are configured to conduct the ion beam **104** towards the substrate **116**. In this regard, the position of the substrate **116** may differ from the position shown in FIG. **2**, such as shown in FIG. **1**. Details of the operation of the ground electrode assembly **206** are discussed below.

In one example of operation of the adjustable accel/decel column **118**, the ion beam **104** may be extracted from ion source **102** using an extraction electrode **230** at a target extraction voltage, such as 50 kV. This voltage may provide an adequate extracted beam current for the ion beam **104** immediately adjacent the ion source **102** in order to deliver a target beam current or beam dose to the substrate **116**. The adjustable accel/decel column **118** may adjust the initial beam potential of ion beam **104** generated by the extraction electrode **230** by changing the voltage (potential) of the extracted ion beam in order to impart a target energy to the ion beam **104** for implantation. In the case where an initial (extracted) beam potential of ion beam **104** is 50 kV, and the target implant energy for ion beam **104** is 250 kV, the following potentials may be set at different components. The body of the ion source **102** may be set at +250 kV, while the extraction electrode **230** used to extract the ion beam **104** from the ion source **102** is set +200 kV. The terminal electrode **202** may, but need not, be set at +200 kV. The ground electrode **210** as well as substrate **116** may be set at ground potential (0V), while the focus electrode may set at an inter-

mediate voltage, such as +100 kV. Thus, as the ion beam **104** traverses the adjustable accel/decel column **118**, the ion beam **104**, when comprising positive ions, may be accelerated from an initial beam potential of +200 V to a beam potential of 0 V, resulting in an increase in ion energy from 50 keV to 250 KeV for singly charged ions. In this example, regardless of any further deceleration performed by other beamline components (not shown) between the ground electrode **210** and the substrate **116**, the final energy of ion beam **104** at the substrate **116** is 250 keV, since the ground electrode **210** and substrate **116** are at the same potential.

A separate power supply (not shown) may be coupled to the ion source **102**, extraction electrode **230**, terminal electrode **202**, and focus electrode **204** in order to provide a targeted voltage (potential) independently to the different components. Moreover, the base **208** and ground electrode **210** of the ground electrode assembly **206** may be maintained at ground potential.

As further shown in FIG. **2**, the ground electrode **210**. is disposed adjacent the focus electrode **204**, meaning there are no other electrodes between the focus electrode **204** and ground electrode **210**. As noted, one function of the focus electrode **204** may be to treat the ion beam **104** to shape the beam in a targeted manner. The focus electrode **204** may help maintain a target shape, size, beam emittance, collimation, divergence, or convergence of the ion beam. Between the focus electrode **204** and ground electrode **210**, an electric field is produced where the field strength may be varied according to the difference in potential applied to the ground electrode **210** and focus electrode **204**. In the above example, a potential difference of 100 kV (+100 kV on focus electrode and 0V on ground electrode **210**) may produce a strong electric field between the ground electrode **210** and the focus electrode **204**.

In order to avoid arcing or other breakdown of the adjustable accel/decel column **118** resulting from an excessive electric field, it may be useful to set the gap or spacing S between the ground electrode **210** and focus electrode **204** at a relatively larger distance. In accordance with the present embodiments, the ground electrode assembly **206** is configured so the ground electrode **210** is reversibly movable with respect to the base **208**, and thus movable with respect to the focus electrode **204**. The focus electrode may accordingly be deemed a fixed electrode. As shown in FIG. **2**, the ground electrode **210** may be movable with the aid of support members **212** along the axis **214**, where the axis **214** lies parallel to the Z-axis as shown. In different embodiments, the ground electrode **210** may be movable between endpoints characterized by a first position P**1** and a second position P**2**. In some embodiments, the ground electrode **210** may be movable between discrete positions, such as a series of two, three, or four positions including P**1** and P**2**. The embodiments are not limited in this context. In other embodiments, the ground electrode **210** may be continuously movable over a range of positions between endpoints represented by a first position P**1** and second position P**2**. In other words, the position of ground electrode may be moved to any set position between P**1** position and P**2**, and may stably remain and operate at the set position.

In various embodiments, the ground electrode **210** may be movable along the axis **214** over a range spanning 100 mm. In other embodiments the ground electrode **210** may be movable along the axis **214** over a range spanning 150 mm. The embodiments are not limited in this context. In particular embodiments, the ground electrode **210** may be movable with respect to a fixed electrode such as focus electrode **204**. In this manner, the ground electrode **210** may be separated from the focus electrode **204** along the axis **214** by a first spacing s greater than 100 mm when the ground electrode **210** is disposed in a first position P**1** (first endpoint) and may be separated from the focus electrode **204** by a second spacing less than 30 mm when the ground electrode **210** is disposed in the second position P**2** (second endpoint). The ability to move the ground electrode **210** with respect to the focus electrode provides multiple advantages as detailed below.

The movement of the ground electrode **210** may be controlled by the drive system **120** discussed earlier. The drive system **120** may include a user interface (not shown) to receive a user selection of parameters such as a position of ground electrode **210**, voltage applied to focus electrode **204**, or other parameters. The drive system **120** may also include a component or components to adjust the position of the ground electrode **210**. In one example, a drive motor or drive motors (not shown) may be provided to move the ground electrode **210** with respect to the base **208** and with respect to the focus electrode **204**. The drive motor may be configured to continuously vary position of the ground electrode **210** continuously between P**1** and P**2**. In another example, a pneumatic system (not shown) may be coupled to the ground electrode **210**, so the pneumatic system may place the ground electrode **210** is a series of discrete positions including P**1** and P**2**.

Returning to the example where the potential at terminal electrode **202** is 200 kV, and the potential at focus electrode **204** is 100 kV, it may be useful to place the ground electrode **210** at or near the position P**1**, resulting in a spacing S of 150 mm in one example. In this manner, since the electric field (E) extending between the ground electrode **210** and focus electrode **204** is proportional to $\Delta V/S$, (ΔV=100 kV−0 kV=100 kV in this example) the electric field E may be maintained at an acceptable level for avoiding arcing or breakdown. For a given ion source condition of ion source **102**, a given extraction potential applied to the extraction electrode **230**, terminal electrode potential applied to terminal electrode **202**, and a given focus electrode potential applied to focus electrode **204**, the beam current transmitted by the adjustable accel/decel column **118** may decrease for an increase in S. Accordingly, in some embodiments of the disclosure, the target value of S may be empirically determined based upon a tradeoff between increased beam current for lower values of S and increased reliability at higher values of S.

In conventional accel/decel column structures where the electrodes are stationary with respect to one another, when an accel/decel column is designed the separation between electrodes may be set to ensure reliable operation at the highest operating implant voltage, including, for example, the neighborhood of 300 kV. In such conventional accel/decel column hardware, the value of S, being fixed, may be relatively larger, such as 100 mm to 150 mm. In contrast, when operating at lower implantation voltages, such as 20 kV, a separation S of 150 mm may be unnecessarily large, since the voltage difference between focus electrode and ground electrode in such a circumstances may be on the order of 10 kV. At a voltage difference of 10 kV between ground electrode and focus electrode, arcing may not occur at distances greater than 20 mm or so. Accordingly, in such a fixed electrode configuration of an accel/decel column, the beam current transported through the accel/decel column may be unnecessarily reduced by the unnecessarily large value of the separation S.

An advantage afforded by the present embodiments includes the ability to tailor the separation S in accordance with ion implantation energy and beam current of the ion beam **104** received by the adjustable accel/decel column **118**. Accordingly, for relatively higher implant energies, such as 175 keV to 300 keV, the position of the ground electrode **210** may be adjusted closer to the position P**1**, so the spacing S

may has a relatively larger value, e.g., between 100 mm to 150 mm. The embodiments are not limited in this context. For intermediate energies such as between 70 keV and 160 keV, the position of the ground electrode **210** may be moved closer to the position P**2**, where the spacing S ranges between 50 mm and 100 mm. This practice may allow the electric field strength in the gap between the focus electrode **204** and the ground electrode **210** to be set at a maximum value where electric breakdown is not caused, in order to improve focus of the ion beam **104**. This maximum value may maximize the beam current of ion beam **104** output to the substrate **116** while avoiding risking arcing or other electrical breakdown in the adjustable accel/decel column **118**. The embodiments are not limited in this context.

For relatively lower implant energies, such as 2 kV to 30 kV, the spacing S may be maintained at a relatively smaller value, such as between 20 mm to 50 mm. Again, with this relatively smaller spacing S the amount of beam current output to the substrate **116** may be increased in relation to larger values of S, while avoiding the risk of breakdown. The embodiments are not limited in this context.

The present inventors have investigated the effects of varying separation S on the beam current delivered by an adjustable accel/decel column arranged according to embodiments of the present disclosure.

In one series of experiments a boron (B+) ion beam of 5 keV energy was delivered to a substrate in an ion implanter where the position of a ground electrode was moved from a large separation S of 102 mm, characteristic of a conventional accel/decel column, to an intermediate separation of 63 mm, and to a small separation of 24 mm. At the large separation a 0.82 mA was delivered at the substrate at a region of interest (ROI). At intermediate separation, a beam current at ROI was 1.31 mA, while at the small separation, the beam current at ROI was 1.54 mA. Accordingly, by adjusting the position of the ground electrode to be closer to the focus electrode than in conventional apparatus, the 5 keV B+ beam current increased 88%, from 0.82 mA to 1.54 mA.

In additional investigations, model-based simulation was performed using a 70 keV As+ beam transported through an acceleration/deceleration column, for different ground electrode positions with respect to a focus electrode. In the case of a large separation of 102 mm, the beam current of a 70 keV As+ beam transported through the beam-line was 18 mA, while in the case of a small separation of 51 mm the beam current of a 70 keV As+ beam transported through the beam-line was 26 mA.

The beam current delivered to a substrate may thus be maximized by minimizing the spacing S between ground electrode and focus electrode. The target spacing S for a given ion beam may be set in consideration of additional factors beyond the consideration of maximizing beam current. For example, with reference again to FIG. **1** and FIG. **2**, when an ion implanter **100** is operated for low energy beams in the 2 keV to 40 keV energy range, the position of the ground electrode **210** may be adjusted within the range between position P**1** and position P**2** to an optimal position so the ion beam **104** has minimum emittance before entering analyzer magnet **106**.

In various additional embodiments, an accel/decel column may include additional components to those illustrated in FIG. **2**. FIG. **3**A, FIG. **3**B, and FIG. **3**C illustrate operation of an accel/decel column **302** according to additional embodiments of the disclosure. The accel/decel column **302** includes a terminal electrode **304**, focus electrode **306**, ground electrode **310**, suppression electrode **314**, tube lens **318** and base **320**. The ground electrode **310** and base **320** may form part of a ground electrode assembly set at ground potential. The suppression electrode **314** may include a suppression electrode aperture (not separately shown). The suppression electrode **314** and tube lens **318** may be biased with a potential negative with respect to ground in some examples. Also shown in FIG. **3**A, FIG. **3**B, and FIG. **3**C is a focus electrode aperture **308**, ground electrode aperture **312**, and an analyzer magnet **322**. As illustrated, the ion beam **104** is generally conducted from left to right in the figures. During the transit the ion beam **104** is extracted from the ion source **102** and processed by the accel/decel column **302** before entering the analyzer magnet **322**.

As shown in the figures, the accel/decel column **302** also includes a plurality of support members, shown as support members **324**, and being affixed to the base **320**. The ground electrode **310** may be reversibly movable with respect to the base **320** with the aid of support members **324**. In some embodiments motor drives may be provided to move the ground electrode **310** along the axis **214** with respect to the base **320**. The ground electrode **310** may also comprise a plurality of sleeves, shown as sleeves **316**. The sleeves **316** may be attached to the ground electrode **310** and circumferentially disposed around the support members **324**, respectively. The sleeves **316** may be slidably movable with respect to the support members **324** along the axis **214**. In the examples of FIG. **3**A, FIG. **3**B, and FIG. **3**C, the sleeves **316** are disposed at the position P**3**, position P**4**, and position P**5**, respectively. As illustrated, at the position P**3** the ground electrode **310** may abut against the base **320**, while at position P**5**, the ground electrode may extend at a furthest distance from the base **320**. On the other hand, at the position P**3**, the spacing S**3** along the axis **214** between the ground electrode **310** and focus electrode **306** is a maximum, the spacing S**4** at the position P**4** is an intermediate value, while the spacing S**5** at the position P**5** is a minimum.

As further shown in FIGS. **3**A-**3**C, the suppression electrode **314** may be disposed within the ground electrode **310** and may be coupled to the ground electrode **310** so the suppression electrode **314** moves in concert with the ground electrode **310**. The suppression electrode **314** may be configured to apply a suppression electrode potential in a range of −3 kV to −10 kV to the ion beam **104** to suppress electrons for preventing radiation.

As also depicted in FIGS. **3**A-**3**C, the tube lens **318** includes two parts including a first portion fixed in position (shown as a right portion in FIGS. **3**A-**3**C). The tube lens **318** also includes a second portion (shown in FIGS. **3**A-**3**C as a left portion) disposed around the first portion and coupled to the ground electrode **310**. Thus, the left portion of the tube lens **318** is not affixed to the right portion of the tube lens **318** so the left portion is slidably movable with respect to the right portion. In particular, the left portion of the tube lens **318** may move in concert with movement of the ground electrode **310** while the right portion remains fixed, so the length of the tube lens **318** may be adjusted. The tube lens **318** may be configured to apply a tube lens potential in a range of −3 kV to −40 kV to the ion beam **104** when the ion beam **104** passes through the tube lens **318** and has an energy in a range of 2 keV to 40 keV in order to shape the ion beam **104**. When beam energy of the ion beam **104** is above 40 keV, the tube lens **318** may be configured to apply a ground potential to the ion beam **104**.

In the aforementioned embodiments, the position of a movable electrode such as a ground electrode may be adjusted in response to user input in a drive system including any convenient user interface, such as a keyboard, keypad, touchscreen, or other device. Moreover, the position of a ground electrode may be controlled in different ways according to different

embodiments. For example, in some implementations, a user may explicitly select a ground electrode position at a user interface. In this manner, a user may specify a target ground electrode position to be employed, and thus adjust the ground electrode position by entering a position value causing the drive system to move the ground electrode to the specified position.

Alternatively, an ion implanter may be pre-calibrated to allow a corresponding ground electrode position to be predetermined for a given implant energy corresponding to a final beam voltage. In this implementation, a user may be provided merely with a selection of voltages to be applied to one or more components of the ion implanter, such as the implant voltage, terminal electrode voltage, focus electrode voltage, and so forth. Once a voltage parameter(s) is specified, the drive component may be configured to automatically move the ground electrode to a first predetermined position. When voltage is subsequently adjusted, the drive component may be configured to automatically move the ground electrode from the first predetermined position to a second predetermined position

FIG. **4** depicts exemplary operations involved in a method according to embodiments of the disclosure. At block **402**, an ion beam is generated using an ion source. The ion beam may be extracted at an extraction voltage adequate to produce a target initial beam current. At block **404**, a ground electrode of an adjustable accel/decel column is arranged at a first position. At block **406**, when the ground electrode is disposed at the first position, a first fixed electrode potential is applied to the ion beam by a fixed electrode of the adjustable accel/decel column disposed upstream of and adjacent to the ground electrode. The fixed electrode may be a focus electrode in various embodiments. At block **408**, a second fixed electrode potential is applied to the ion beam by the fixed electrode, where the second fixed electrode potential is less than the first fixed electrode potential. At block **410**, user input is received at in a drive component. The user input may be a selection of a position for the ground electrode. At block **412**, the ground electrode is moved to a second position wherein the ground electrode and fixed electrode define a first gap in the first position and a second gap in the second position smaller than the first gap.

In summary, the adjustable accel/decel column of the present embodiments may provide various advantages. For example, a first advantageous effect involves increasing the available beam current provided to a substrate over a range of ion energies, a second advantageous effect involves providing a convenient approach to adjusting electrode separation in an accel/decel column, while a third advantageous effect involves the ability to optimize beam optics of an accel/decel column for operation over a range of ion energies and beam currents.

The present disclosure is not to be limited in scope by the specific embodiments described herein. Indeed, other various embodiments of and modifications to the present disclosure, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such other embodiments and modifications are in the tended to fall within the scope of the present disclosure. Furthermore, the present disclosure has been described herein in the context of a particular implementation in a particular environment for a particular purpose, yet those of ordinary skill in the art will recognize the usefulness is not limited thereto and the present disclosure may be beneficially implemented in any number of environments for any number of purposes. Thus, the claims set forth below are to be construed in view of the full breadth and spirit of the present disclosure as described herein.

What is claimed is:

1. An apparatus to control an ion beam for treating a substrate, comprising:

a fixed electrode configured to conduct the ion beam through a fixed electrode aperture and to apply a fixed electrode potential to the ion beam;

a ground electrode assembly disposed downstream of the fixed electrode, the ground electrode assembly comprising:

a base; and

a ground electrode disposed adjacent the fixed electrode and configured to conduct the ion beam through a ground electrode aperture, the ground electrode being reversibly movable along a first axis with respect to the fixed electrode between a first position and a second position, wherein a beam current of the ion beam at the substrate varies when the ground electrode moves between the first position and second position.

2. The apparatus of claim **1**, further comprising a drive component configured to move the ground electrode between the first position and second position responsive to user input.

3. The apparatus of claim **1**, further comprising a plurality of support members affixed to the base, wherein the ground electrode further comprises a plurality of sleeves circumferentially disposed around the plurality of support members, respectively, wherein the plurality of sleeves are slidably movable with respect to the plurality of support members along the first axis.

4. The apparatus of claim **1**, wherein the fixed electrode is a focus electrode configured to shape the ion beam, the apparatus further comprising:

a terminal electrode disposed upstream of the focus electrode, configured to conduct the ion beam through a terminal electrode aperture and to apply a terminal electrode potential to the ion beam;

a suppression electrode having a suppression electrode aperture disposed downstream of the ground electrode aperture, the suppression electrode configured to apply a suppression electrode potential to the ion beam to suppress electrons for preventing radiation; and

a tube lens disposed at least partially within the ground electrode assembly and configured to apply a tube lens potential to the ion beam.

5. The apparatus of claim **4**, wherein the tube lens comprises a first portion and a second portion disposed around the first portion and slidably movable with respect to the first portion along the first axis.

6. The apparatus of claim **4**, wherein the suppression electrode potential ranges from −3 kV to −10 kV, and wherein the suppression electrode is movable with respect to the focus electrode along the first axis.

7. The apparatus of claim **1**, wherein the ground electrode is movable between discrete positions including the first position and second position.

8. The apparatus of claim **1**, wherein the ground electrode is continuously movable between the first position and second position.

9. The apparatus of claim **4**, wherein the terminal electrode, fixed electrode and ground electrode assembly comprise an accel/decel column configured to adjust the ion beam to a potential of up to 300 kV with respect to ground.

10. The apparatus of claim **4**, wherein the ground electrode is movable along the first axis with respect to the focus electrode over a distance spanning a range of 100 mm to 150 mm.

11. The apparatus of claim **1**, wherein the ground electrode is separated from the fixed electrode along the first axis by a first spacing less than 30 mm when the ground electrode is disposed in the second position, and by a second spacing greater than 100 mm when the ground electrode is disposed in the first position.

12. The apparatus of claim **1**, wherein a first beam current of the ion beam at the substrate when the ground electrode is in the second position is at least 50% greater than a second beam current of the ion beam at the substrate when the ground electrode is in the first position.

13. An ion implanter, comprising:

an ion source to generate an ion beam for treating a substrate;

an extraction electrode to extract the ion beam at an initial beam potential; and

an adjustable accel/decel column configured to receive the ion beam and to adjust the initial beam potential, the adjustable accel/decel column comprising:

a focus electrode configured to conduct the ion beam through a focus aperture and to apply a focus electrode potential to the ion beam; and

a ground electrode assembly disposed downstream of the focus electrode, the ground electrode assembly comprising a base and a ground electrode configured to apply a ground electrode potential different than the focus electrode potential and configured to conduct the ion beam through a ground electrode aperture, the ground electrode being reversibly movable along a first axis with respect to the focus electrode between a first position and a second position, wherein a beam current of the ion beam at the substrate varies when the ground electrode moves between the first position and second position.

14. The ion implanter of claim **13**, the adjustable accel/decel column further comprising a terminal electrode disposed upstream of the focus electrode and configured to conduct the ion beam through a terminal electrode aperture and to apply a terminal electrode potential to the ion beam.

15. The ion implanter of claim **13**, further comprising a drive component configured to move the ground electrode between the first position and second position responsive to user input.

16. The ion implanter of claim **13**, further comprising a plurality of support members affixed to the base, wherein the ground electrode further comprises a plurality of sleeves disposed around the plurality of support members, respectively, wherein the plurality of sleeves are slidably movable with respect to the plurality of support members along the first axis.

17. A method of manipulating an ion beam, comprising:

generating the ion beam using an ion source;

arranging a ground electrode of an adjustable accel/decel column at a first position;

applying a first fixed electrode potential to the ion beam at a fixed electrode of the adjustable accel/decel column disposed adjacent to and upstream of the ground electrode when the ground electrode is disposed at the first position;

applying a second fixed electrode potential less than the first fixed electrode potential to the ion beam at the fixed electrode; and

responsive to user input in a drive component, moving the ground electrode to a second position, wherein the ground electrode and fixed electrode define a first spacing in the first position and a second spacing smaller than the first spacing in the second position.

18. The method of claim **17**, wherein the ground electrode is configured to move continuously between the first and second positions, wherein the ground electrode is configured to stably operate at a plurality positions intermediate the first position and second position.

19. The method of claim **17**, wherein the user input comprises selection of the second fixed electrode potential, wherein the drive component is configured to automatically move the ground electrode from the first position to the second position responsive to receipt of the second fixed electrode potential.

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